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SPACEWATCH®: Following up Near-Earth Objects (NEOs) to help Determine their Orbits

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An impact by an asteroid or comet onto the Earth is one of the few natural disasters that can be predicted in advance and that we have the tools to prevent. Without sufficient follow-up observations during their discovery apparitions, NEOs often accrue large uncertainties in position during typical intervals between apparitions. Some NEOs can become effectively "lost" when their positional uncertainties are large enough such that they are more likely to be rediscovered by chance than to be recovered by observations targeted to their ephemerides (Milani 1999). SPACEWATCH®, which pioneered using CCDs to survey the sky for NEOs, currently conducts Near Earth Object (NEO) follow-up observations. To improve planetary defense capabilities by reducing the uncertainty in NEO orbital elements, we conduct full-time rapid astrometric follow-up observations of high priority NEOs as the sole users of the Lunar and Planetary Laboratory's Spacewatch 1.8-m observatory and the Steward Observatory's 0.9-m telescope on Kitt Peak. Additionally, we conduct astrometric follow-up with Steward Observatory's Bok 2.3-m telescope during bright time with the Spacewatch Cassegrain Camera (SCC) (see Table 1).

Our highest priority targets for NEO astrometric follow-up are virtual impactors (VIs) and Potentially Hazardous Asteroids (PHAs). PHAs are ≥140 meters in diameter with Earth Minimum Orbit Intersection Distances (EMOIDs) ≤ 0.05 au. VIs have sufficiently uncertain heliocentric orbital parameters such that at least one orbit solution predicts an Earth impact within 100 years. PHAs pose a greater hazard due to their size, but the majority do not have orbits in which the asteroid could impact Earth itself. VIs pose a greater impact risk due to their real (but low) probability of impact. Currently, only ~1% of NEAs on the JPL Sentry risk list of VIs are "large" (>140 m). It is particularly important to minimize the orbit uncertainties for VI PHAs to rule out (or in) possible impacts.

Spacewatch has observed a majority of the newly discovered NEOs that are or were on JPL's VI impact risk list since October 16, 2019. According to the PDS SBN, from Sept. 1993 through March 2025, the 1.8-m is third in making the first observation for follow-up MPECs, sixth in follow-up MPECS, and fifth over all types of MPECs. It is fifth in MPECs for making the first follow-up observation over the past year. The 0.9-m is sixth in discovery MPECs and eighth in precovery MPECs from September 1993 through March 2025. SPACEWATCH® also leads in faint observations (V>22.0) as shown in Figure 1.

In addition to our regular follow-up observations, SPACEWATCH® has a Target-of-Opportunity program for recovery of potential impactors. This includes applying for open time at larger telescopes (4 to 8m class), such as the LBT, the MMT, Gemini North and South, CTIO Blanco, Keck, and SOAR. The observations are triggered when a Virtual Impactor

becomes too faint to follow up with smaller class telescopes, is large enough to be dangerous, and still has a high impact probability and/or high Palermo Scale value. ToO measurements of VI 2022 LX illustrate the benefit of using a large telescope to recover a VI. It was discovered on 2022 May 22 and observations were collected by smaller telescopes through July 5 while it was V < 23. We triggered a ToO with LRIS on Keck I on 2022 July 28 to extend the timespan of its observations by 23 nights. After we submitted our astrometry to the Minor Planet Center (MPC), the orbital recalculation led to a decrease in the orbital element uncertainties by ~30% (Table 2) and ruled out the potential impacts.

In 2019, SPACEWATCH®, Catalina Sky Survey (CSS) and the University of Minnesota began the Bok NEO Survey, a collaborative survey program using 90Prime on the Bok 2.3-m Telescope to discover faint asteroids, especially larger NEOs and Earth Trojan candidates. New discoveries include the imminent impactor 2024 XA1 which broke up in the atmosphere over Siberia, the hyperbolic Comet C/2025 D1 (Gröller) and Apollo NEA 2025 EW3 which has a diameter of 860m (possibly larger). From the start of the Bok NEO survey on November 15, 2019 through April 10, 2025, the observatory was operational for 48.5 months over which we averaged an allocation of 7.2 nights per month of dark/grey time from Steward Observatory. NASA's Planetary Data System's Small Bodies Node's MPEC Watch reports that of the top MPEC'd discoverers, this survey is fourth over the past 5 year and is sixth since September 19, 1993. Of the top MPEC'd precoverers, it is eighth over the past year and ninth over the past 5 years (https://sbnmpc.astro.umd.edu/mpecwatch/index.html).

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